Free space optical data links using cat's eye modulating retro-reflectors

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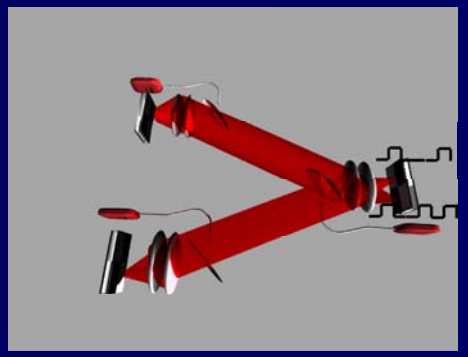
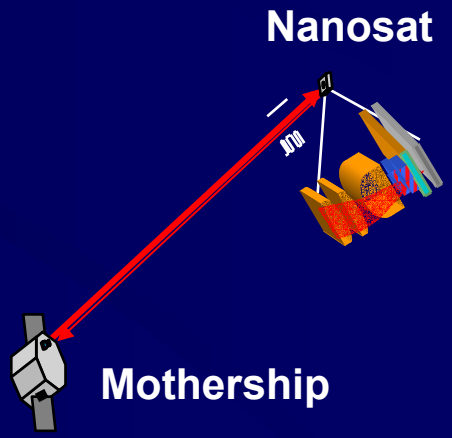
Goals of the Work

- Enable free space optical (FSO) links with reduced pointing requirements using cat's eye modulating retro-reflectors

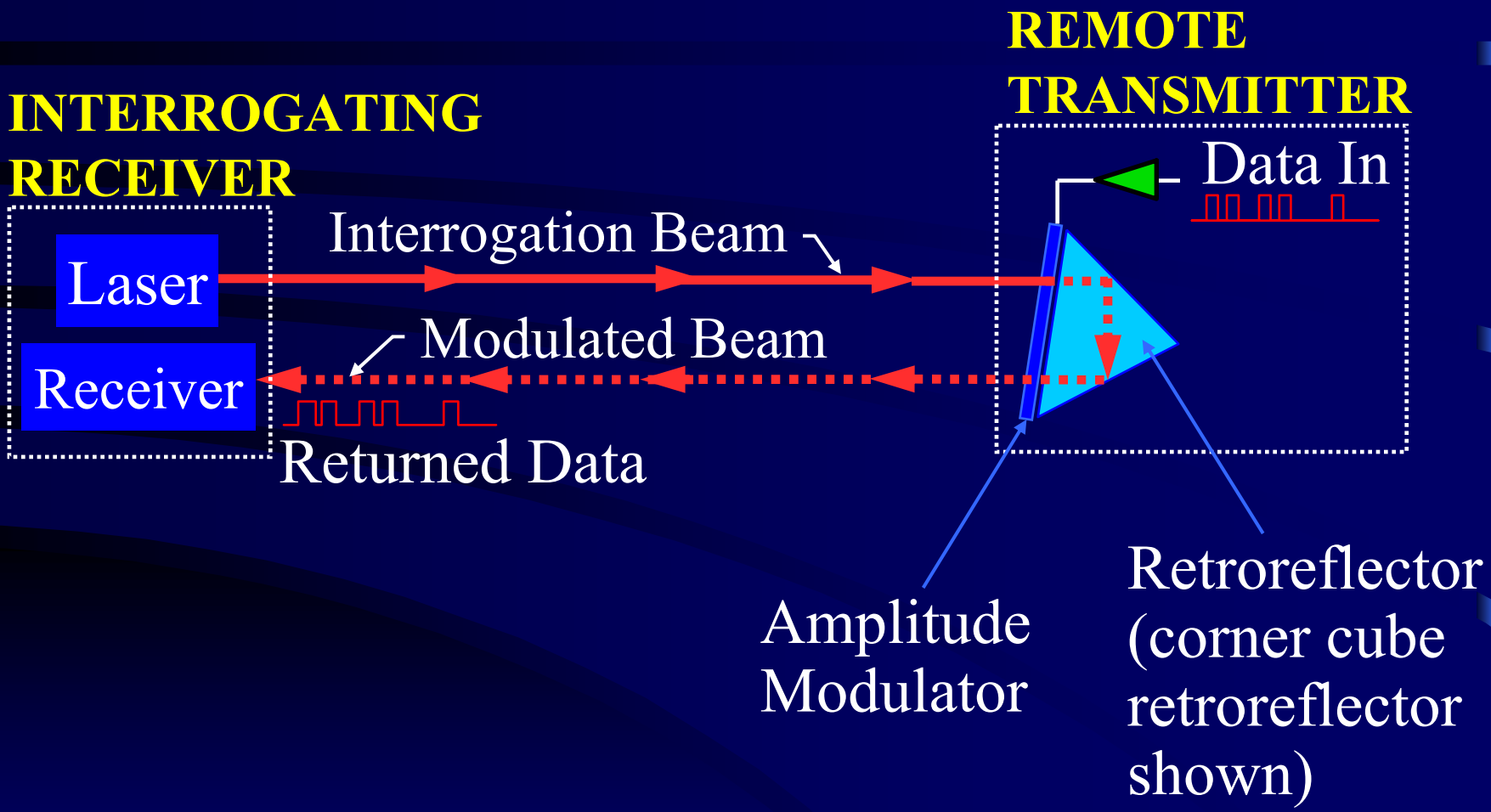


- Short range symmetric links
  - Replace on board hard wired data links with FSO links
  - Identical non diffraction limited cat's eyes on both end

- Long-range asymmetric links
  - Inter-spacecraft (mothership to nanosatellite) links
  - Actively pointed lasercomm terminal on mothership
  - Diffraction-limited cat's eye on nano-satellite

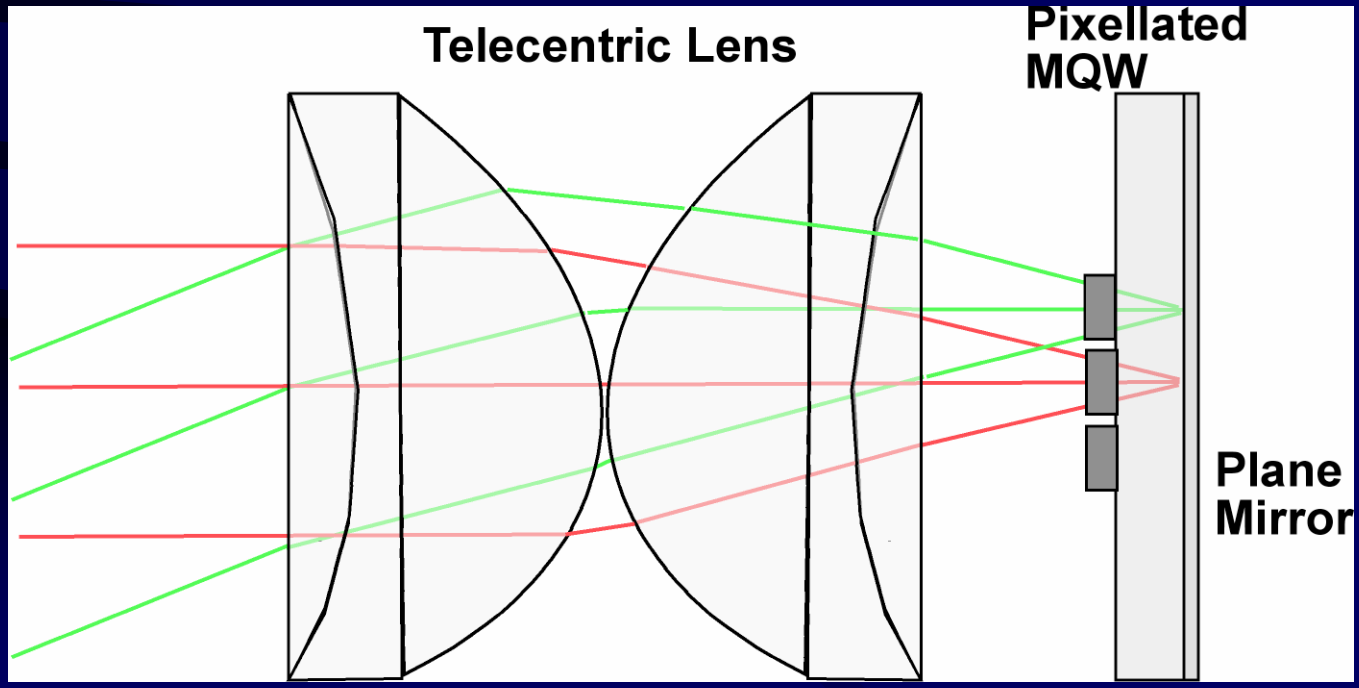


What is a Modulating Retroreflector?

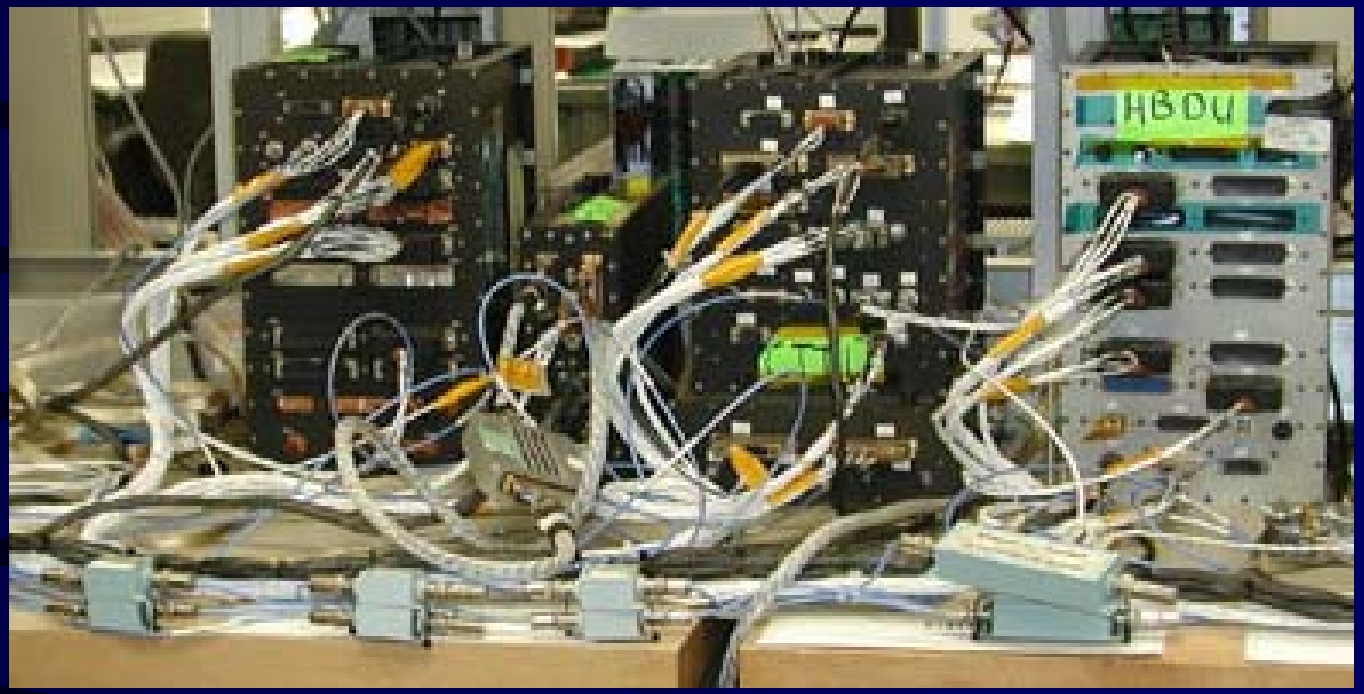


A simple cat's eye MRR

- A telecentric lens with a flat reflector in the focal plane is a cat's eye retro-reflector
  - Telecentric lenses produce a symmetric ray bundle regardless of incident angle
  - The mirror inverts the ray bundle and hence retro-reflects



Can We Replace This?



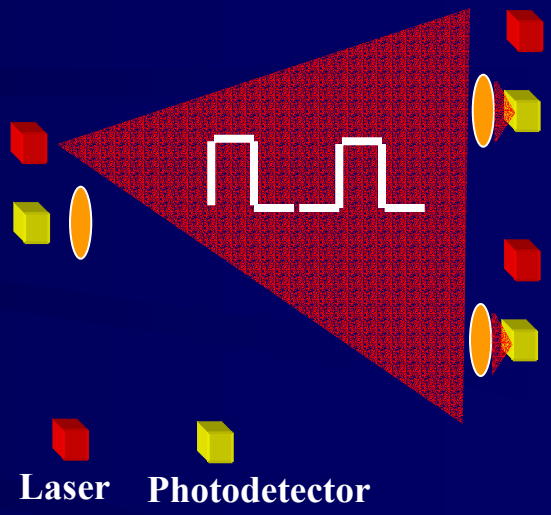
A large portion of the Terra C&DH
(Command and Data Handling) system
Engineering Developmental models (backup for flight)

Alternative Approach

- Free space optics (FSO) could enable:
  - Lower weight
  - Higher data rates
  - Flexible topologies (insert new instruments w/o new cabling)
  - Insensitivity to RF interference
  - Possible further extension to inter-spacecraft optical communication

Broad Beam Interconnect

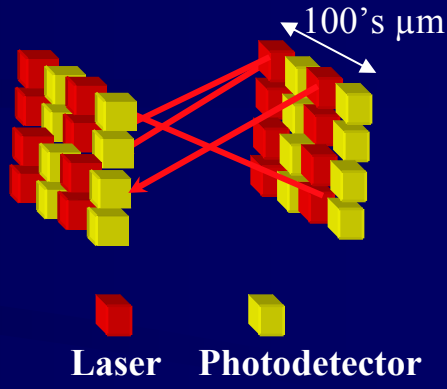
(*e.g.* TV remote)



- Pros:
  - + Low sensitivity to alignment
  - + Simple
- Cons:
  - – "Broadcasts" data everywhere
    - Can't send or receive different data to different nodes simultaneously
  - – Moderate data rate
    - No Angular multiplexing capability

Micro-optical FSO Interconnect

- Pros:
  - + Very high data rates possible
- Cons:
  - – *Extremely* tight alignment tolerances
    - limited practical range, reliability questionable



Cat's Eye Modulating Retroreflector (the method used)

Pros:

+ Relaxed alignment tolerances

+ Can make use of angular multiplexing for high aggregate data rates

- Cons:

– Single channel data rates moderate, although multiple channels can operate simultaneously without degrading individual channel bandwidth

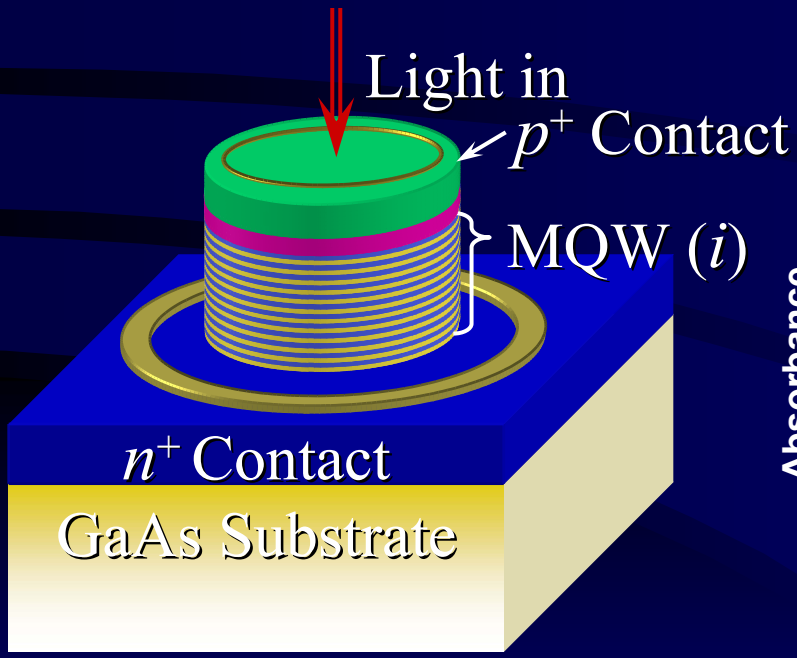
Cat's Eye vs. Micro-optical Link

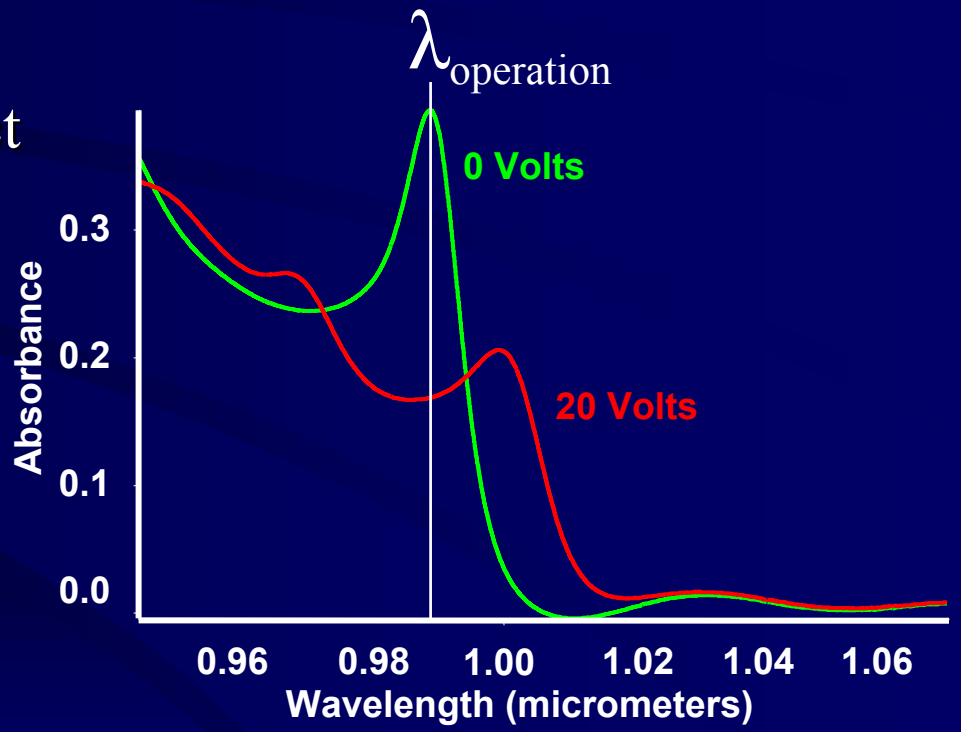
	Micro optical free-space link	Cat's eye retroreflector
Angular sensitivity	0.01 degrees	3.0 degrees
Positional sensitivity	0.5 mm	~100 mm
Optical efficiency	-12 dB	-30 dB

This approach trades laser power for reduced alignment sensitivity.

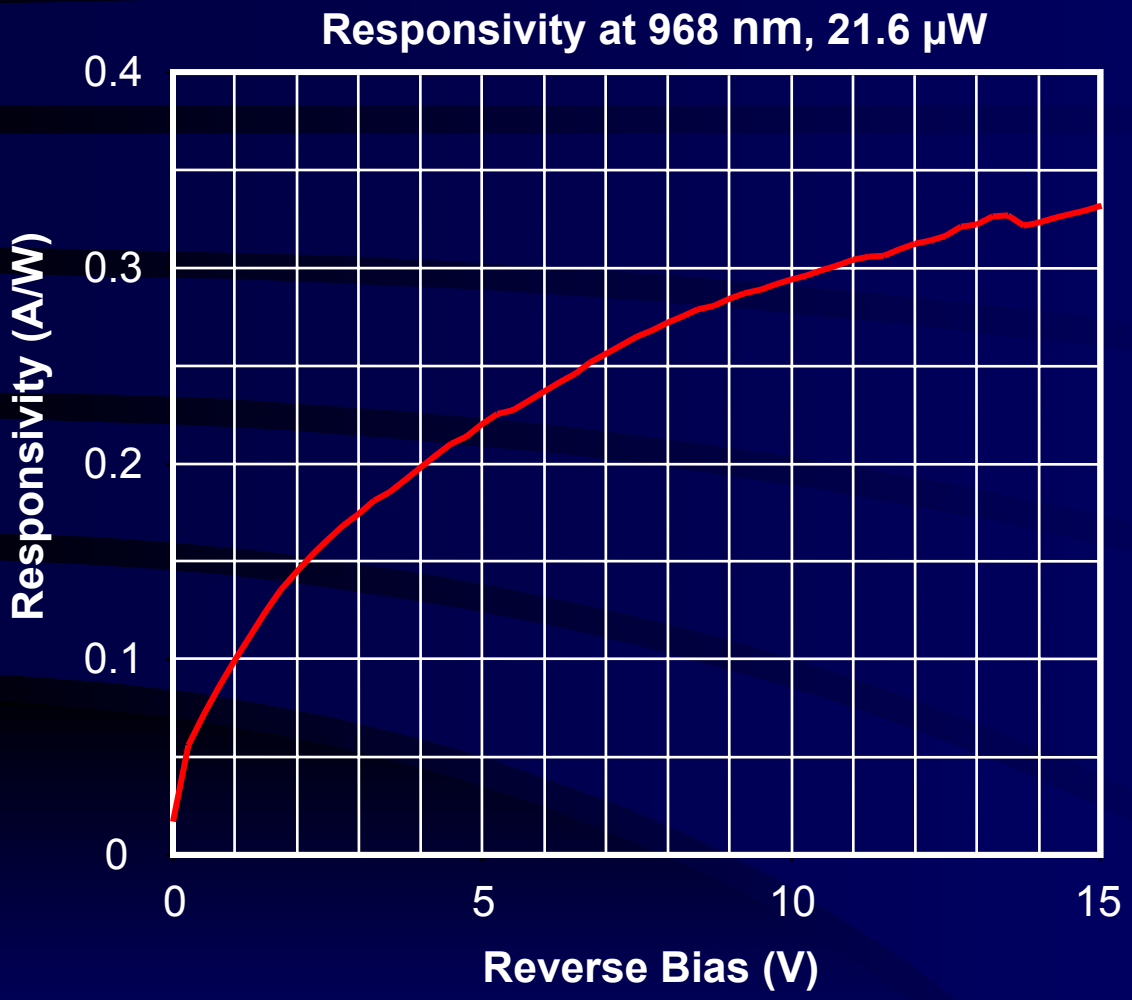
MQW Modulators

- Absorption of light changes when voltage applied
- No sensitivity to angle or polarization
- Wavelengths from 0.85 μm to 1.55 μm have be used



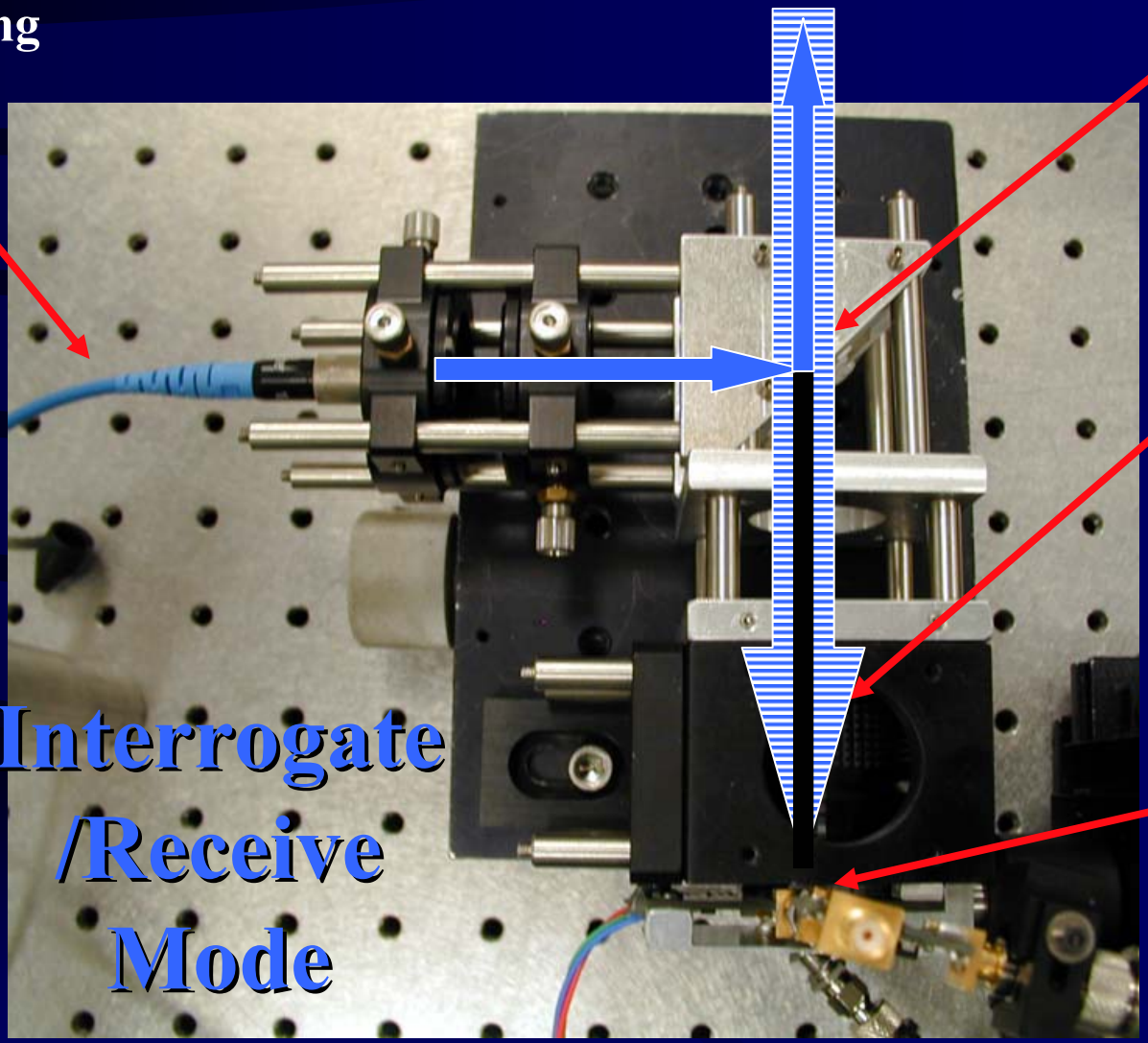


MQW Used As Photodiode

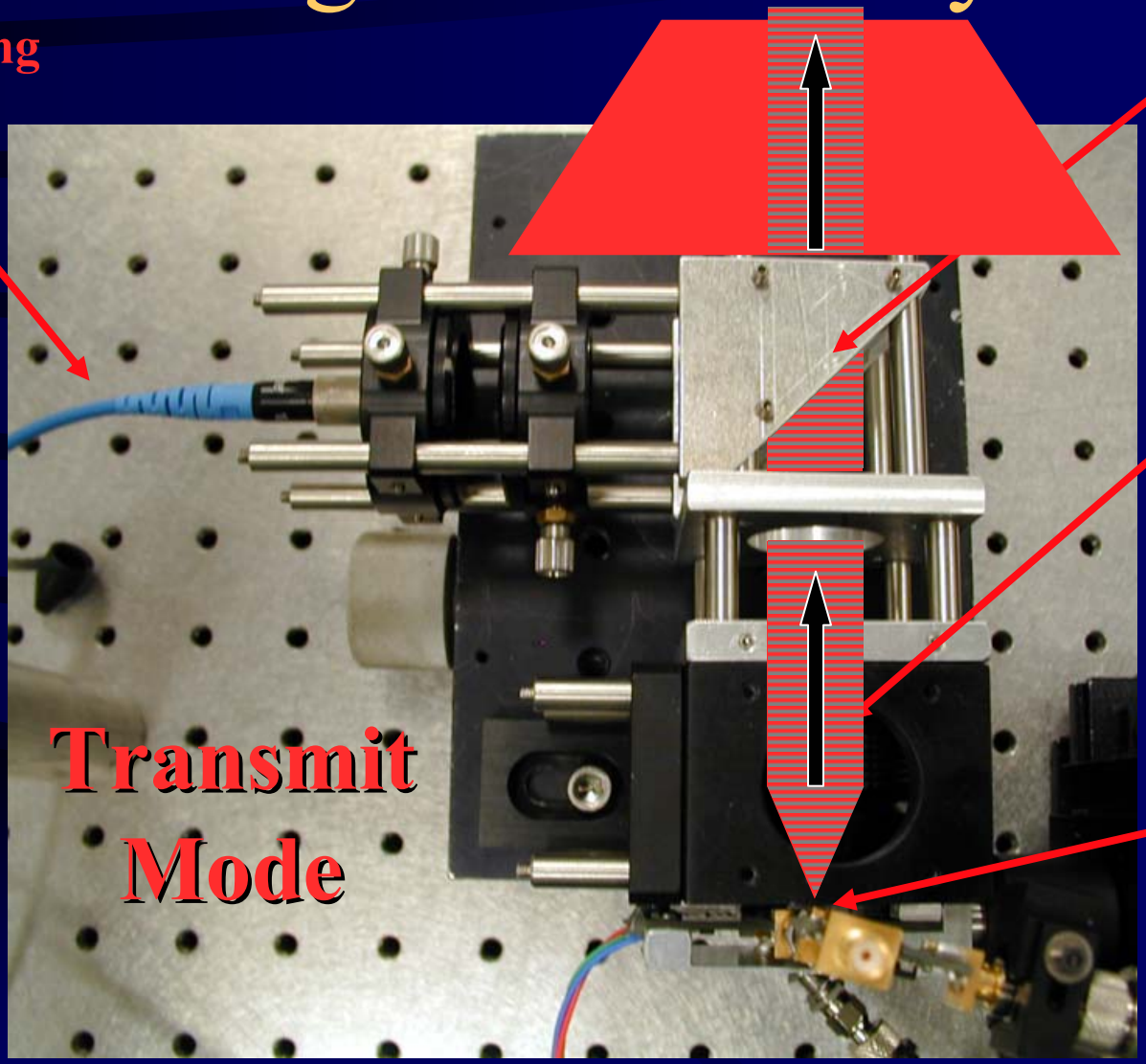


Modulator is a *p-i-n* diode, can be used as a photodiode too!

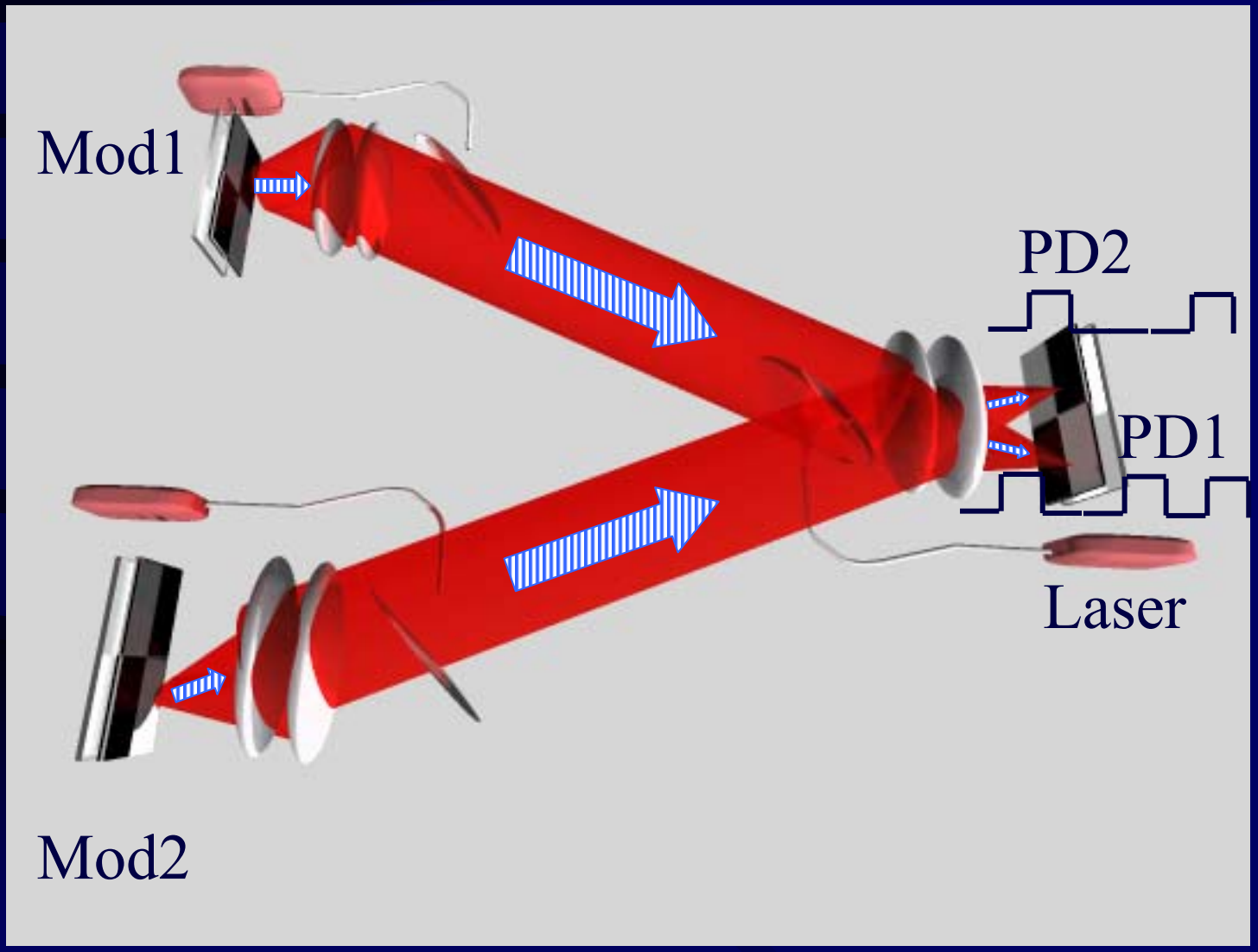
Integrated Cat's Eye



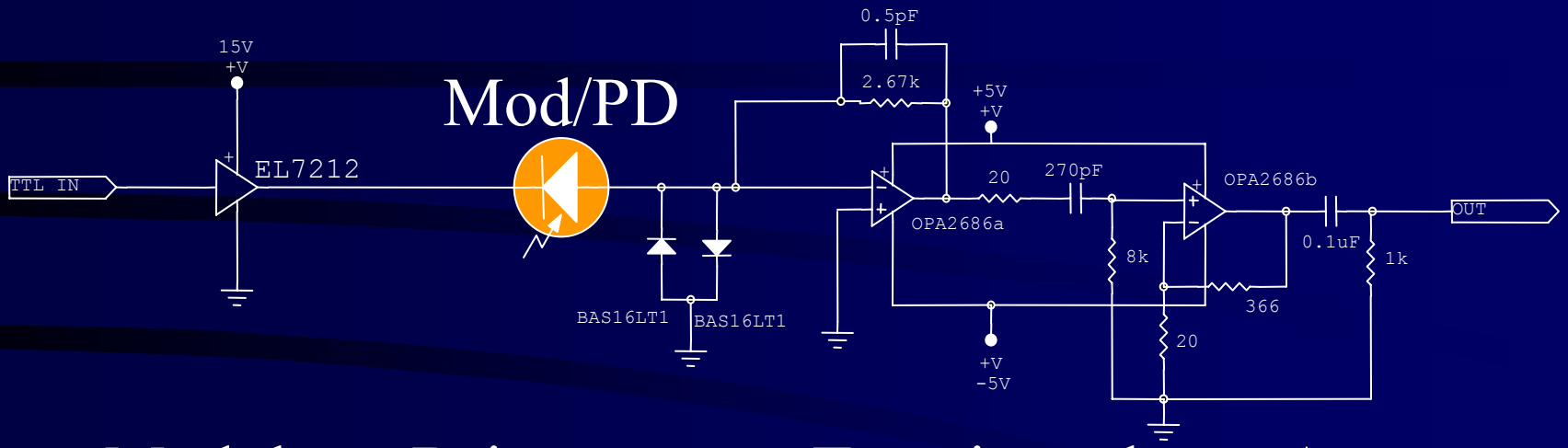
Integrated Cat's Eye



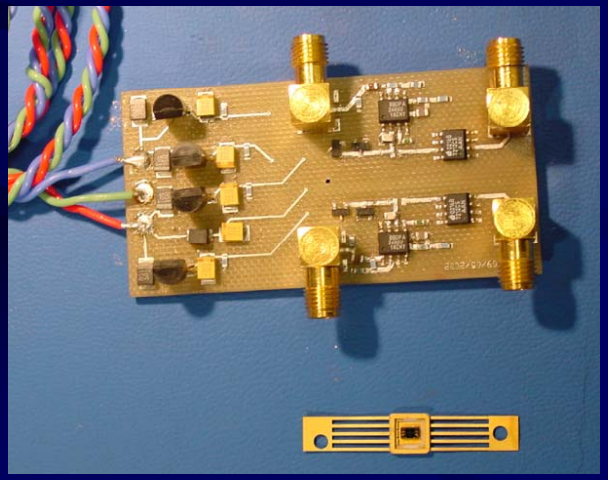
Point to Point Cat's Eye Link



Circuitry for Modulator/photodiode Operation

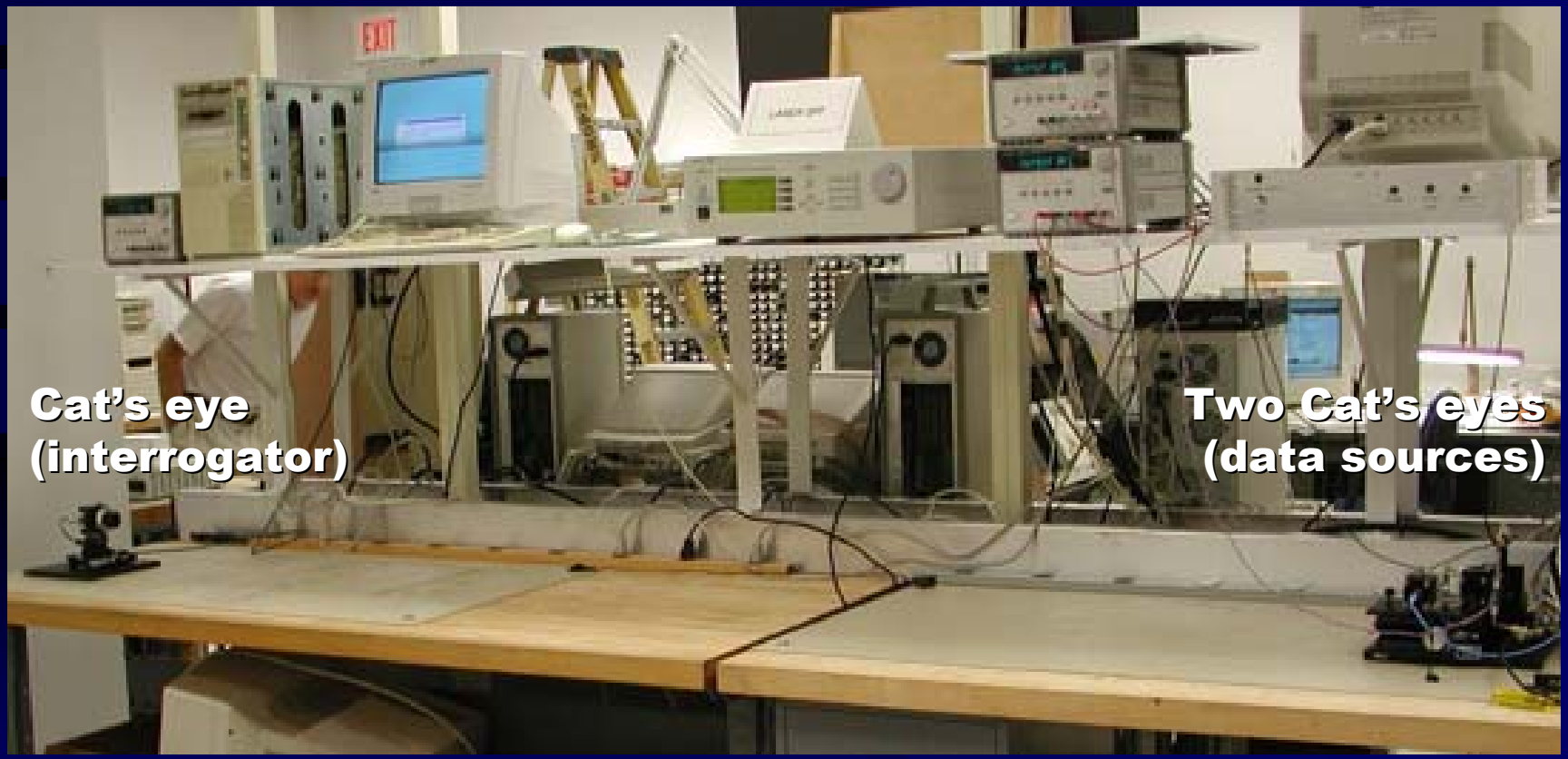


Modulator Driver Transimpedance Amp

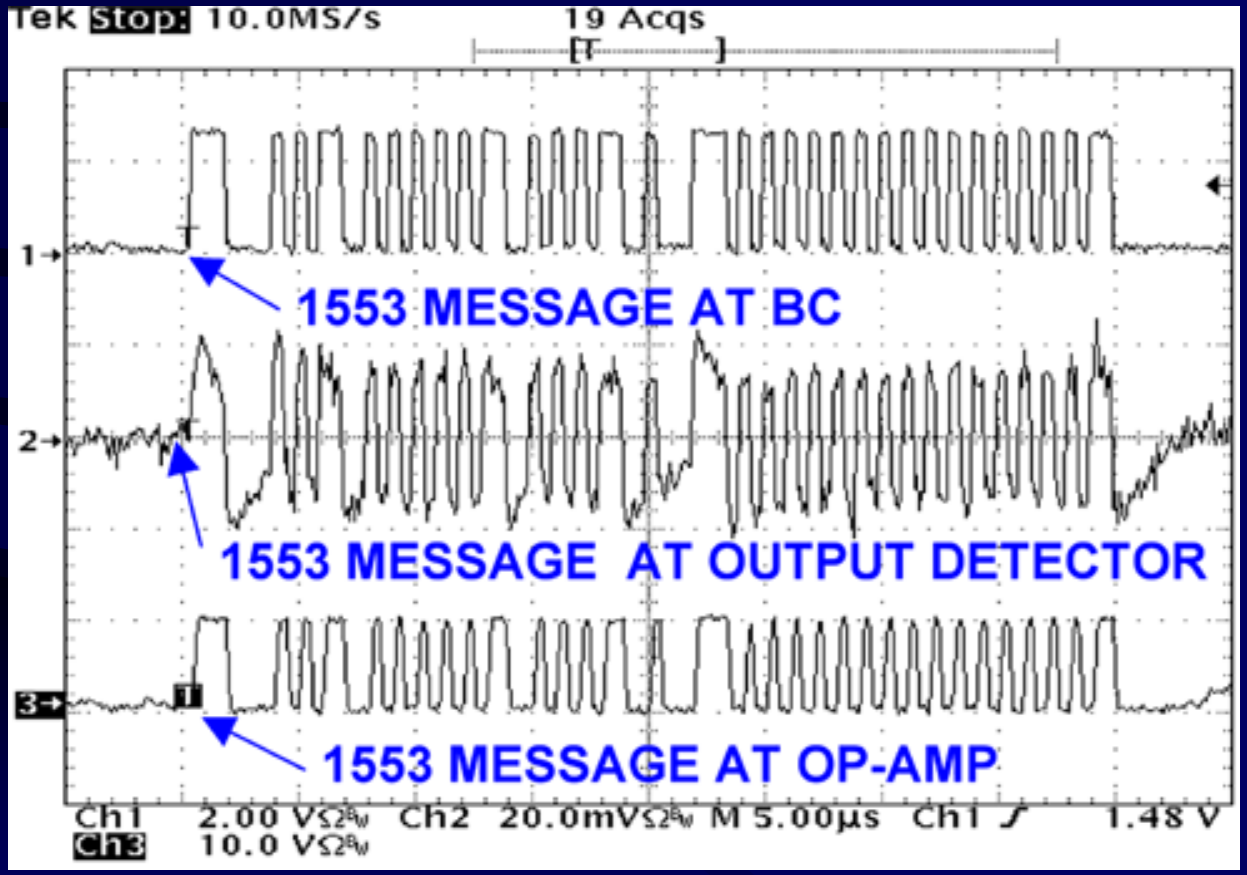


1553 Cat's Eye Link

- A 3 node 2 way cat's eye 1553 link has been set up over a 3 meter path



1553 Waveform Transmitted Over 3 Meter Cat's Eye Link

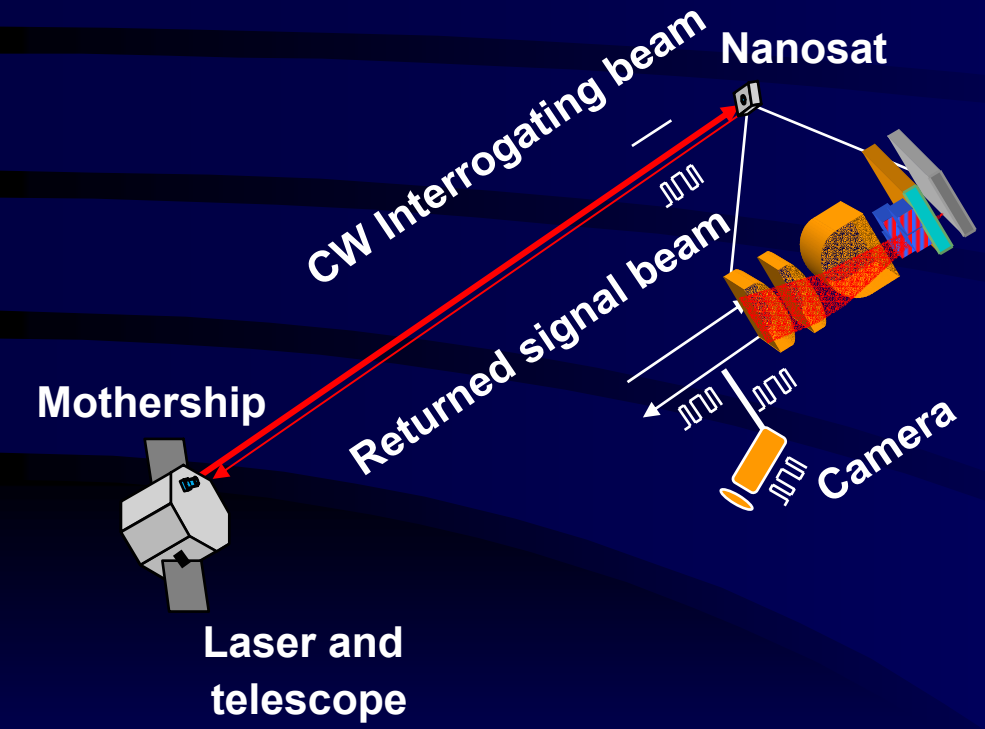


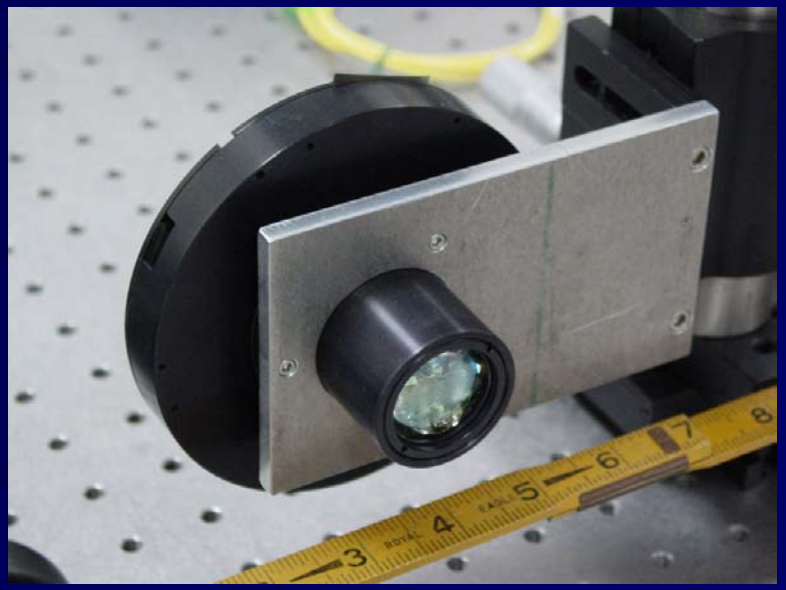
1553 Protocol

- 1553 is ubiquitous but not well matched to optical hardware
  - limited to single channel operation
  - limited to 1 Mbps
  - Inflexible

- With alternative protocols this type of hardware is capable of
  - Single channel data rates of 100 Mbps
  - Aggregate data rates > 1 Gbps

Diffraction-limited Cats' Eye for Inter-spacecraft Data Transfer

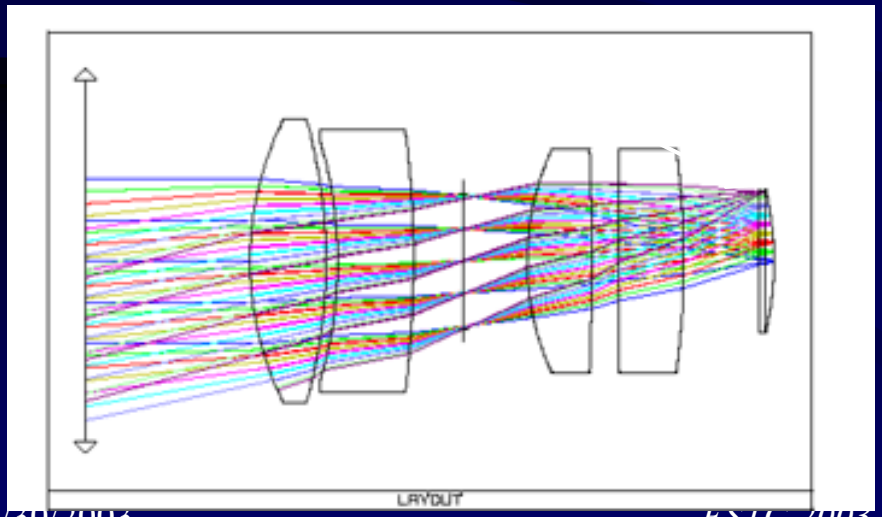




20 dB more return than simple cat's eye

Diffraction-limited Cat's Eye

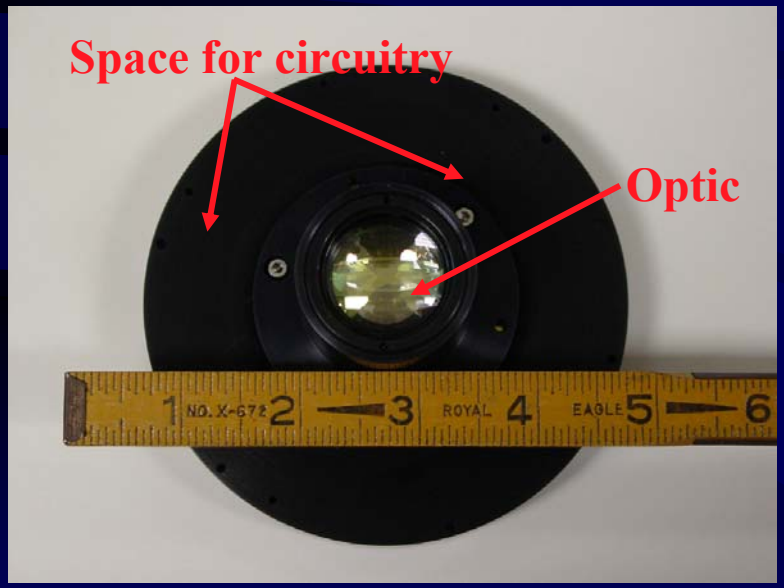
- Custom cat's eye optical design
  - 5 element NRL design with one aspheric component
- Optical characteristics
  - 1.6 cm aperture
  - f/1.6
  - 30 degree FOV
  - Diffraction limited

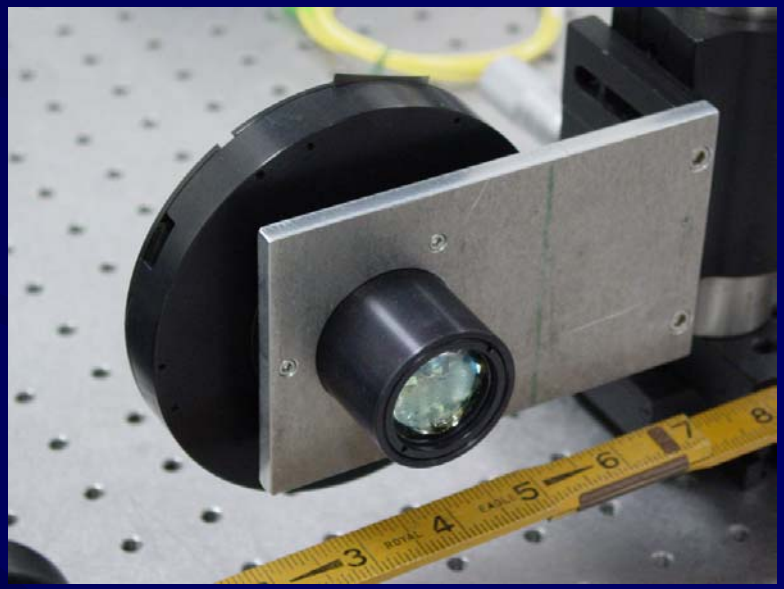


Custom Cat's eye design

Fabricated Diffraction Limited Cat's Eye

- Custom cat's eye fabricated
  1 micron operating wavelength





Switched cat's eye focal plane

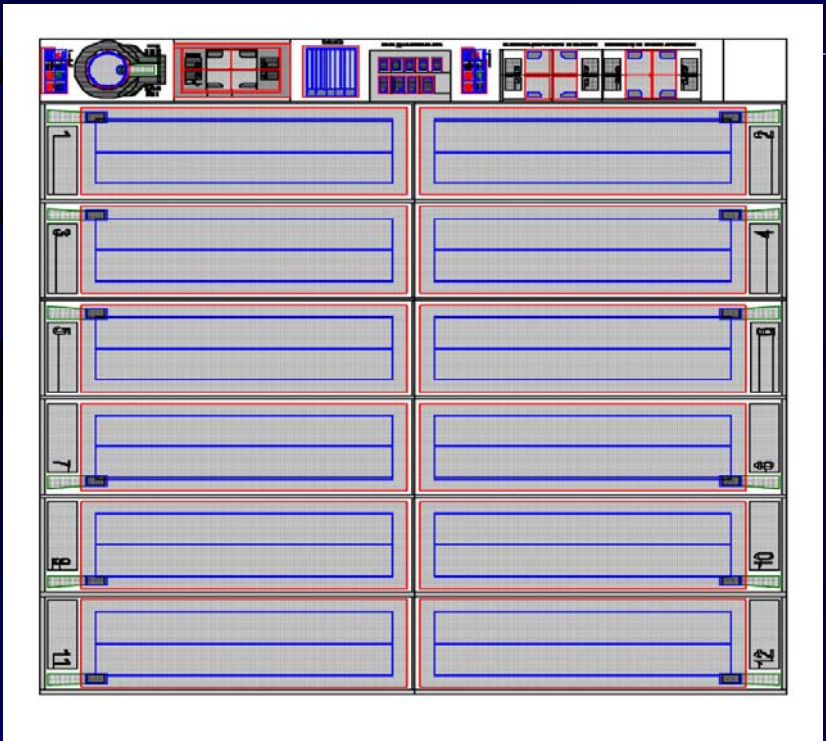
- For an inter-spacecraft link the platform's relative positions are not constant
  - The Optical spot will move in focal plane

- Two ways to handle this:
  - Spacecraft with positions and attitude known to within a couple of degrees
    - Programmed cat's eye
  - Spacecraft with unknown positions and attitude
    - Use cat's eye itself as angle of arrival sensor
    - Switch to illuminated pixel

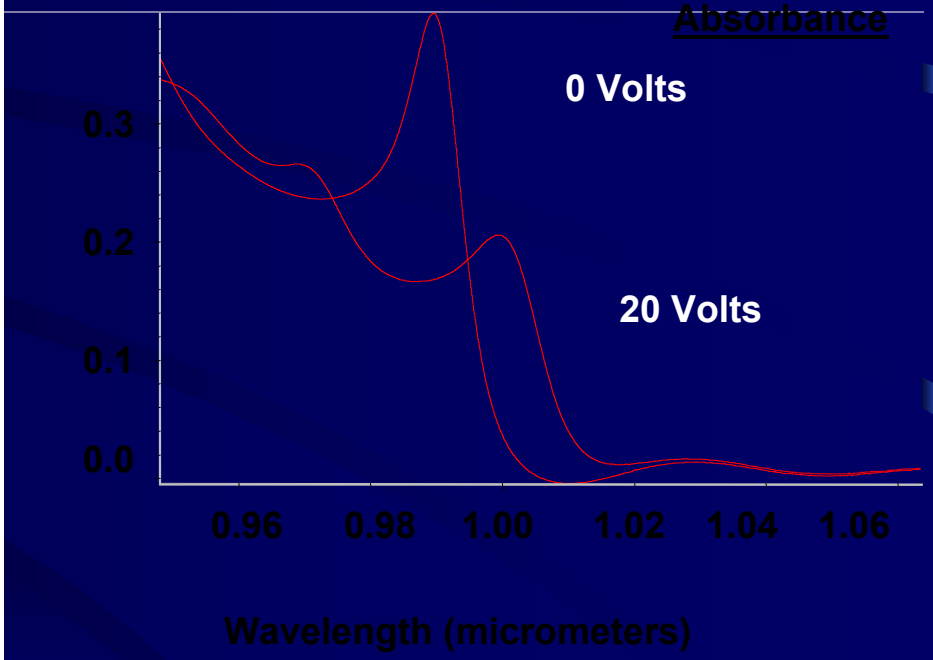
- In this work we have implemented the first solution

MQW Focal Plane

- 4x2 and 6 x 2 rectangular pixel arrays of MQW modulators fabricated
  - 8x8 mm size, covers 17° FOV
  - 10 Mbps bandwidth
- New MQW structure: better modulation contrast



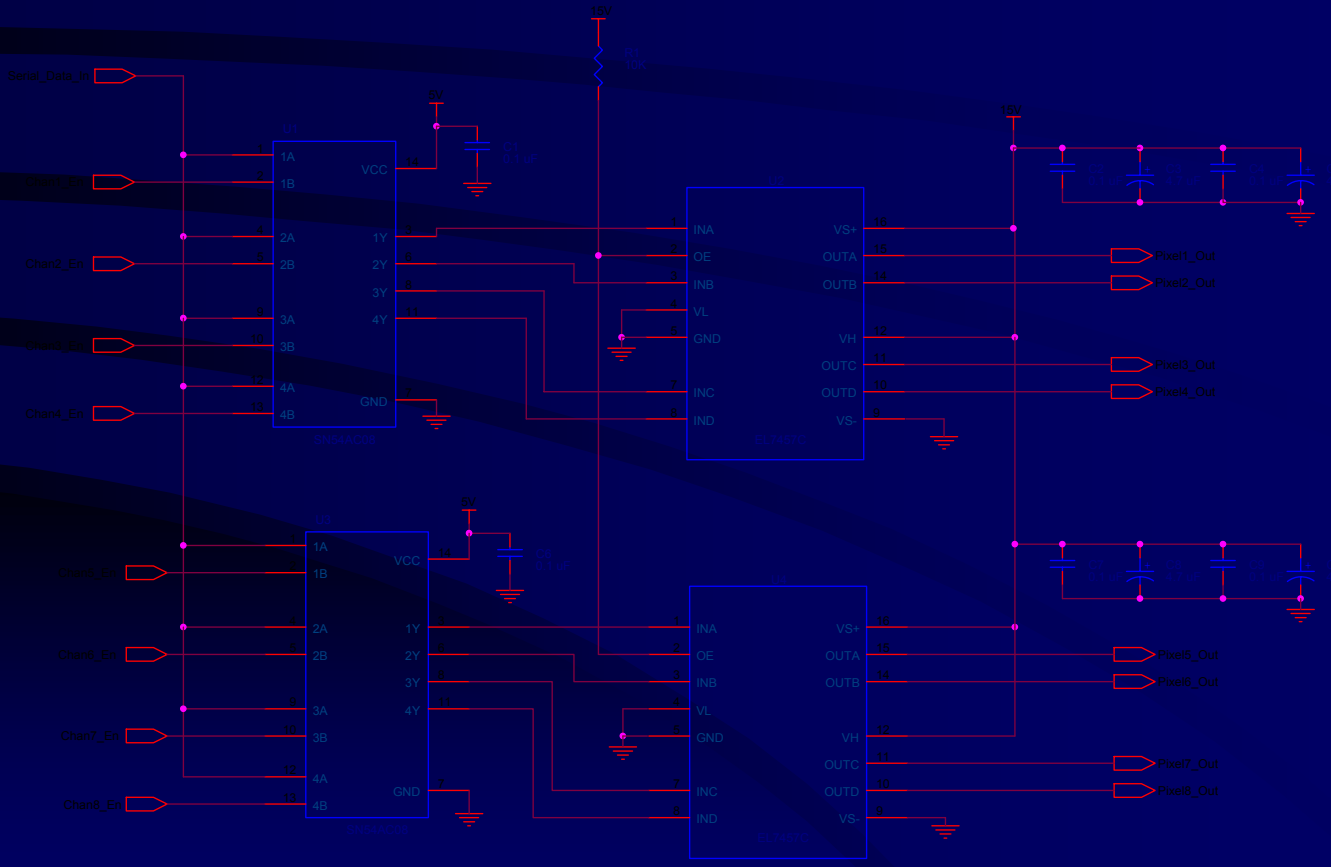
Photolithography mask



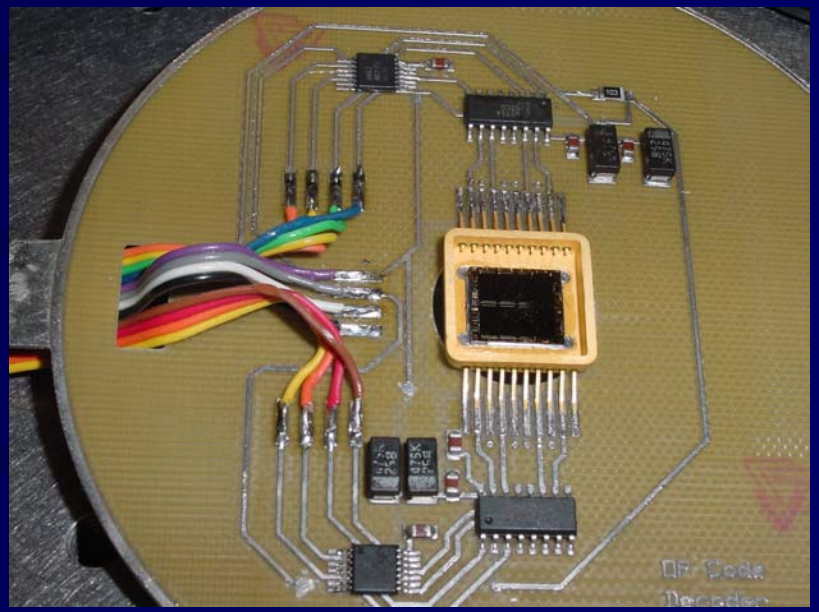
MQW electroabsorption

Diffraction limited cat's eye driver electronics

- The cat's eye is driven by a small microprocessor to turn on the correct pixel at the correct time
- Two versions of the diffraction-limited cat's eye electronics have been built
- Below is the discrete version

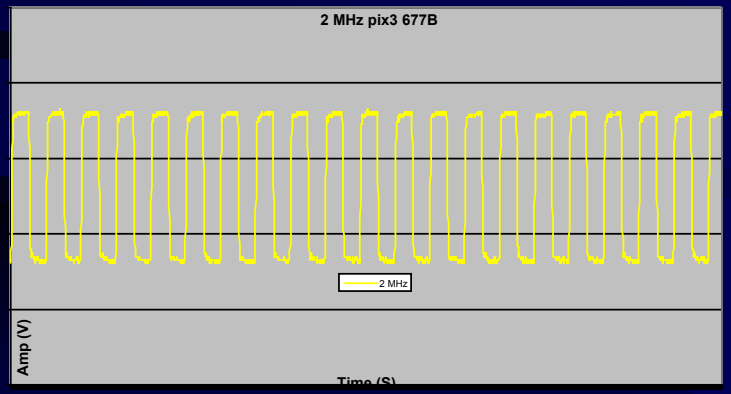


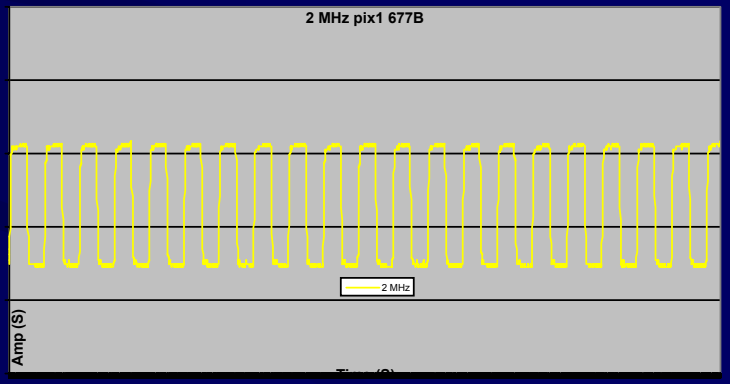
Cat’s eye MRR



Cat’s eye focal plane testing

Pixels were programmed to switch on in ten second sequences





Diffraction limited cat's eye status

- Optics and electronics designed, fabricated and tested
  - Works as planned
- Current design can support
  - data rates up to 10 Mbps
  - FOV of test unit is 17 degrees limited by array
  - Programming of arbitrary array modulation pattern verified

Sample space to space link

Range:100 Km

Data rate: 155 Mbps

Cat's eye modulating retro

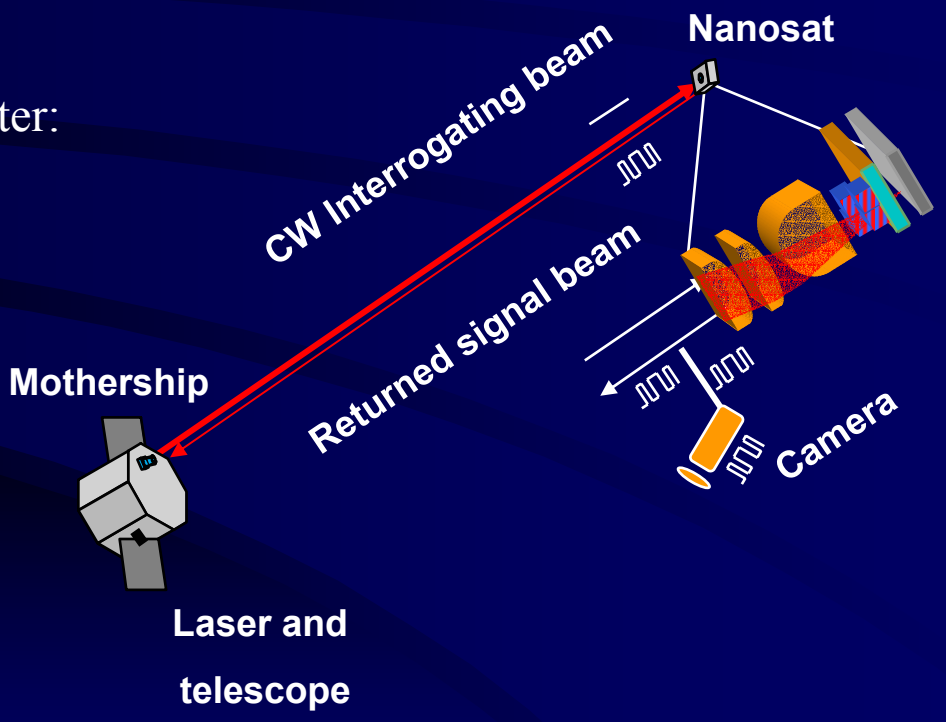
1.6 cm diameter

Power consumption: 0.1 Watts

Mothership transmitter:

20 cm telescope

10 Watt transmitter



Summary

- Two way MIL-STD-1553 cat's eye link demonstrated
  - Potential for much higher aggregate data rate with alternative protocols
- Diffraction limited cat's eye tested
  - Capable of interspacecraft links

We acknowledge the support of the NASA Earth Science Technology Office